

Evolution of Gigantic Jets at high temporal and spatial resolution[✉]

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ABSTRACT: Gigantic Jets (GJ) are lightning discharges between the cloud and the lower ionosphere, which manifest as leaders at low altitude and transition to streamers as they rise in altitude. The evolution has never been imaged before at rates faster than 1/60th second. We ran a campaign in northern Colombia with an intensified high-speed camera at 900 images per second to study the development. The image sequence reveals a weakly luminous stepwise upward propagation from the cloud top to 40 km altitude, after which continuous and much brighter branches grow to the ionosphere in 2 ms. We show the stepping to be consistent with pilot system propagation in streamers.

INTRODUCTION

How lightning which starts inside the cloud transforms into a gigantic jet consisting of streamers as it reaches higher altitudes has been subject of recent modelling studies (e.g. Raizer et al. 2007; Da Silva and Pasko, 2013). The thought is that the heating required for leader channels is no longer effective, while streamers become increasingly longer with reduced atmospheric density, and jump to the ionosphere once they become longer than the atmospheric scale height. The remainder of the event typically shows a luminous lower jet channel topped by beads (45-65 km altitude) moving upward slowly (e.g. Soula et al. 2011).

From May to December 2016, a simple low-light camera installed in Santa Marta at the north coast of Colombia was operated remotely and registered 5 gigantic jet events. For the 2017 season a portable intensified fast camera system (900 fps) was assembled in order to resolve better the evolution of the jet. It was triggered by a sensitive camera with 2.3 megapixel Sony IMX174 sensor and 25mm F0.95 lens, operated through UFOCaptureHD event detection software. Another system has been remotely operated on the Caribbean island of Curaçao since 2014, but has not been able to record gigantic jets. A campaign was conducted in Santa Marta, Colombia from 29 July – 23 August of 2017. Four gigantic jets were recorded, during two nights, at distances of 345-355 km. The two events of 14 August 2017 were fully recorded by the fast camera. Another interesting event was recorded at just 100 m distance with the fast camera on 23 August, when several complex sprite events were accompanied by trolls – low altitude,

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upward moving streamers.

RESULTS

Very weakly luminous filaments are seen in the “slow” high resolution camera several frames before the fully developed stage of the GJ. The low brightness and marked widening of the filaments match the characteristics of streamers, right as it comes out of the cloud. This was also clearly the case in the events by Soula et al. (2011) and Liu et al. (2015), although the latter assumed based on the observed exponential acceleration, like Da Silva and Pasko (2013), that they were leaders. However, GJ events if photographed in color show marked blue filaments down to the cloud top, characteristic to streamers, as opposed to leaders which thanks to their high temperature have intense emissions across the visible and near-IR spectrum. Leaders, if observed with typical cameras and gain settings used for recording transient luminous events, totally overexpose and bloom when recorded at distances less than 100 km. Here, in fact, a leader channel appears - like in many gigantic jets - at the very end of the event, as a bright narrow channel within the trailing jet channel below 25 km.

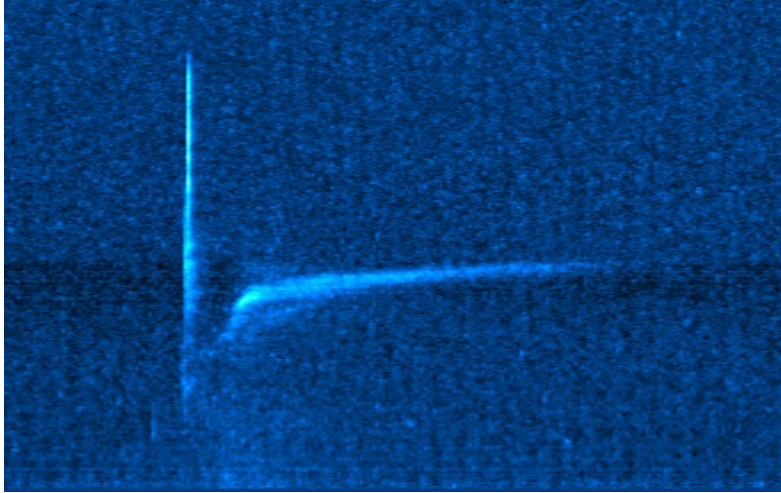


Figure 1. Time-altitude-brightness plot of GJ3 derived from the fast camera, along the gigantic jet channel, spanning the time interval -64 ms to 208 ms relative to the fully completed jet, at altitudes above 28 km. Before the full development, at 40-86 km altitude, one clear segment stands out, isolated in time (10 ms), preceded by a more subtle one at lower altitude.

The fast camera images reveal a step-wise upward progression, and a fast final jump from about 50 km altitude of about $2-4 \cdot 10^7 \text{ m s}^{-1}$. The speed during the visible steps is $4 \cdot 10^6 \text{ m s}^{-1}$ and the two dark intervals last 10 ms (in GJ3). The slow camera derived time-averaged upward speed during the leading jet lies between $4 \cdot 10^4 \text{ m s}^{-1}$ and $2 \cdot 10^5 \text{ m s}^{-1}$. The trailing jet has a fast stage of $5-8 \cdot 10^5 \text{ m s}^{-1}$ and a slow stage of $1-3 \cdot 10^4 \text{ m s}^{-1}$ in both GJ3 and GJ4.

CONCLUSIONS

The observed gigantic jets exhibited streamer mode propagation across all visible heights (21-86 km), with a stepping process at intervals on the order of 5-10 ms and steps of 2-5 km at altitudes of 32-40 km.

A journal paper has been submitted with more images, graphs and discussion, including a simulation of stepwise streamer propagation by the pilot mechanism (e.g. Gallimberti et al. 2002; Petersen et al., 2008) to fit the starting potential at the cloud top lightning leader and the combination of electric potential gradient values over the negative and positive streamer zones to match the observed step sizes and altitude of the final jump.

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